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Technical Note: Comparison of the Maresh Reference Data With the WHO International Standard for Normal Growth in Healthy Children

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ABSTRACT The Maresh reference data on stature and long bone lengths in a sample of healthy middle-class children from Denver, Colorado [Maresh: Am J Dis Child 66 (1943) 227–257; Maresh: Am J Dis Child 89 (1955) 725–742; Maresh: Human growth and development (1970) p 155–200], have been used extensively by biological anthropologists to estimate juvenile age and body size using skeletal elements and to assess growth in skeletal series from different ethnic populations or archaeological cultural groups. How well these data reflect the potentially diverse growth patterns of healthy human populations from different geographic areas is unknown. Similarly, the efficacy of using the Maresh reference data to estimate stunting prevalence in prehistoric populations is unknown. This report presents the results from a comparison of the Maresh data on supine length and standing height to the World Health Organization (WHO) international child growth standard. The WHO growth standard is meant to depict typical human growth under optimal conditions and can be used to assess children worldwide, regardless of ethnicity and socioeconomic status. The results from this comparison indicate that although the Maresh reference data generally conform to the WHO standard, reflecting a normal human growth pattern, and therefore serve as a suitable reference for comparative studies of growth patterns, these reference data are not suitable for estimating stunting prevalence. Am J Phys Anthropol 147:493–498, 2012. © 2012 Wiley Periodicals, Inc.

Marion M. Maresh published numerous reports on physical growth and maturation in healthy children as part of a long-term longitudinal Child Research Council Study (Maresh and Deming, 1939; Maresh, 1943, 1948, 1955, 1959, 1961, 1966, 1970, 1972; Hansman and Maresh, 1961). Perhaps best known are her landmark reports on the linear growth of long bones (Maresh, 1943, 1955, 1970). Maresh's assessments of growth were based on measurements taken from radiographs of the extremities, as well as measured supine length and standing height. These reports are particularly valuable because they include individual-level longitudinal (Maresh, 1943) and mixed longitudinal percentile data (Maresh, 1943, 1955) derived from a reasonably large sample of healthy children of largely European descent from Denver, Colorado. Additionally, this dataset provides lengths including and excluding the epiphyses; the latter of which is needed for osteological comparisons. Biological anthropologists have come to rely on these reports collectively as an important modern reference dataset for the study of long bone growth in modern, historic, and prehistoric skeletal populations (e.g., Ryan, 1976; Merchant and Ubelaker, 1977; Buschang, 1982; Lovejoy et al., 1990; Wall, 1991; Hoppa, 1992; Saunders and Hoppa, 1993, Saunders et al., 1993; Thompson and Nelson, 2000; Humphrey, 2003; Smith and Buscang, 2004, 2005; Schillaci et al., 2011; also see review in Hoppa, 2000), as well as for estimating stature and age in juveniles (e.g., Attallah and Marshall, 1989; Feldesman, 1992; Ruff, 2007; Smith, 2007).

The Maresh dataset, comprising measurements taken from roentgenograms of about 175 subjects ranging in age from less than a year to as old as 18 years, has been used extensively in comparative analyses of long bone growth, particularly femoral growth, in archaeologically derived skeletal populations. Despite the importance of this dataset for comparative research, how well it reflects the potentially diverse growth patterns of healthy human populations from different geographic areas is unknown. Because the Maresh dataset comprises children from a presumably middle class socioeconomic grouping of largely European origin, it might be useful to compare those data with an international standard to address questions regarding the potential confounding effects of ethnicity and population-level variability on comparisons of growth.

To date, there have been no published studies comparing the Maresh reference data with a growth standard. As asserted by the WHO (WHO Multicenter Growth Reference Study Group, 2006a, p 77), "[s]trictly speaking, a reference simply serves as an anchor for comparisons, whereas a standard allows both comparisons and

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permits value judgments about the adequacy of growth." The WHO Multicenter Growth Reference Study (MGRS) Group presented a growth standard that describes how children "should" grow when free of disease and reared following healthy practices including adequate nutrition and breastfeeding and a nonsmoking environment (WHO Multicenter Growth Reference Study Group, 2006a, p 77). The WHO standard is based on data collected from healthy children with good nutrition and is meant to depict normal human growth under optimal conditions and can be used to assess children everywhere, regardless of ethnicity, socioeconomic status, and type of feeding (WHO Multicenter Growth Reference Study Group, 2006a, p 83). This standard has been used by researchers to assess and compare growth patterns from various populations worldwide (e.g., Stein et al., 2010).

The WHO growth standard is based on a mixed longitudinal (n = 1,737)/cross-sectional (n = 6,669) sample of healthy boys (n = 3,450) and girls (n = 3,219) from countries around the world, including Brazil, Ghana, India, Norway, Oman, and the United States. A formal comparison of growth among the different international components included in the development of the WHO standard revealed strikingly similar growth patterns, with only 3% of the total variability in body length growth attributable to intersite differences, and 70% of the variation attributable to growth differences among individuals within any given site (WHO Multicenter Growth Reference Study Group, 2006b). The WHO MGRS suggested that this low intersite (i.e., interpopulation) variation in growth indicates either a recent common origin or a strong selective advantage across human environments associated with the observed pattern of growth (WHO Multicenter Growth Reference Study Group, 2006a).

There is a growing literature comparing alternative growth references and their applicability for assessing growth. The central question throughout much of this literature is whether or not assessments of population growth are dependent on the growth reference used. More specifically, do estimates of the prevalence of childhood stunting (e.g., Eckhardt and Adair, 2002; Moestue et al., 2004; Rousham et al., 2011), wasting (de Onis et al., 2006), and obesity (Wang and Wang, 2002) vary according to the growth references used? In a comparison of growth references released by the US Centers for Disease Control and Prevention (CDC) and the National Center for Health Statistics, Eckardt and Adair (2002) found large differences in stunting prevalence for some ages for a sample of presumably undernourished children from the Philippines, despite a general similarity in centile curves. The authors pointed out that internationally stunting prevalence is often used as a population level indicator of children's health status (Eckhardt and Adair, 2002, p 575), and therefore, differences in estimated stunting prevalence calculated using different growth references could present different pictures of the nutritional status of a region's children. Similarly, de Onis et al. (2006) pointed out that differences in estimates of wasting and stunting using different growth references have implications for therapeutic feeding recommendations and broader efforts to monitor and promote infant and child health.

The purpose of the following report is to compare the Maresh dataset on supine length and standing height to the most recent WHO child growth standard to assess its suitability as a reference in the comparative analysis of growth. In particular, how well the Maresh reference data might perform in estimating stunting prevalence is examined.

TABLE 1. Age-specific stature in centimeters from the Maresh (1955) and WHO datasets

	Maresh		WHO[a,b]	
Month	Lowest	50%	50%	Difference (cm)
Boys				
2	52.5	56.7	58.4	−1.7
4	57.8	62.3	63.9	−1.6
6	61.8	66.6	67.6	−1.0
12	69.9	75.1	75.7	−0.6
18	76.3	82.0	82.3	−0.3
24	81.9	86.9	87.5	−0.6
30	86.0	90.4	91.9	−1.5
36	90.4	94.6	96.1	−1.5
42	94.2	98.5	99.9	−1.4
48	98.0	102.2	103.3	−1.1
54	101.5	105.8	106.7	−0.9
60	105.0	109.3	110.0	−0.7
66	107.7	112.7	112.9	−0.2
72	110.2	116.0	116.0	0.0
78	112.5	119.2	118.9	0.3
84	114.6	122.3	121.7	0.6
90	116.5	125.3	124.5	0.8
96	118.5	128.2	127.3	0.9
102	120.5	131.1	129.9	1.2
108	122.7	134.0	132.6	1.4
114	124.7	136.8	135.2	1.6
120	127.3	139.4	137.8	1.6
Girls				
2	50.6	56.0	57.1	−1.1
4	55.2	61.0	62.1	−1.1
6	58.6	64.8	65.7	−0.9
12	66.6	73.7	74.0	−0.3
18	73.1	80.7	80.7	0.0
24	78.6	86.0	86.1	−0.1
30	82.2	89.7	90.7	−1.0
36	86.1	94.1	95.1	−1.0
42	89.9	98.4	99.0	−0.6
48	93.6	102.6	102.7	−0.1
54	97.1	106.5	106.2	0.3
60	100.3	110.0	109.4	0.6
66	103.2	113.5	112.2	1.3
72	105.9	116.7	115.1	1.6
78	108.6	119.9	118.0	1.9
84	111.4	123.1	120.8	2.3
90	114.2	126.3	123.7	2.6
96	116.9	129.5	126.6	2.9
102	119.6	132.7	129.5	3.2
108	122.2	135.8	132.5	3.3
114	124.4	138.7	135.5	3.2
120	126.1	141.2	138.6	2.6

Measured stature/length changes from supine length to standing stature at 24 months for both the Maresh and WHO datasets. Both supine length and standing stature are presented for 24 months; however, these values differ. Therefore, in the current study, the values for 24 months for both the Maresh and the WHO data represent the mean of the reported reclining supine body length and standing height.

[a] WHO data for boys and girls aged 2–24 months are available at: http://www.who.int/childgrowth/standards/lhfa_boys_0_2_percentiles.txt and http://www.who.int/childgrowth/standards/lhfa_girls_0_2_percentiles.txt.

[b] WHO data for boys and girls aged 24–120 months are available at: http://www.who.int/childgrowth/standards/lhfa_boys_2_5_percentiles.txt and http://www.who.int/childgrowth/standards/lhfa_girls_2_5_percentiles.txt.

METHODS

Growth in stature for children aged 2–120 months for the Maresh (1955) reference data was compared with the WHO child growth standard (Table 1). The WHO data

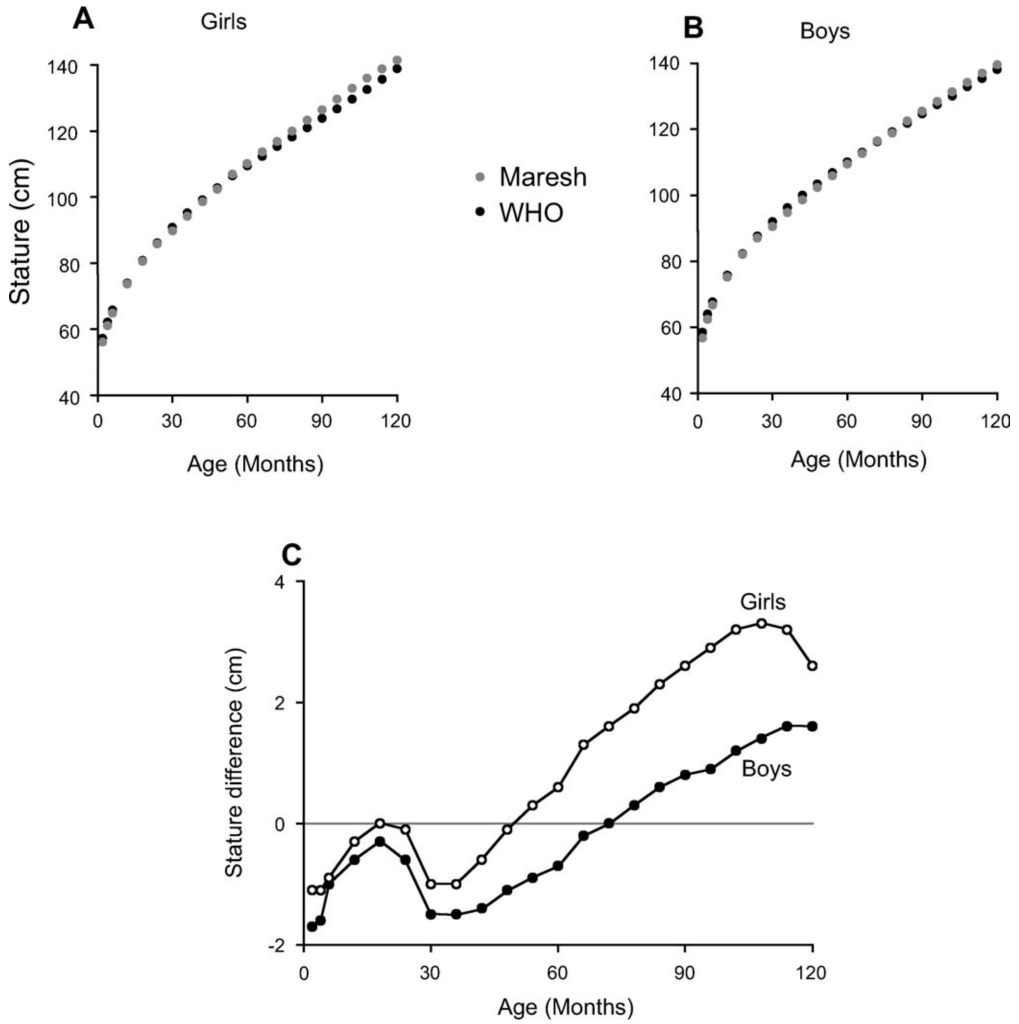

Fig. 1. Bivariate plots of stature for age for girls (A) and boys (B), and the age-specific stature difference from the WHO growth standard (gray line; C).

used in the analysis were restricted to those age categories present in the Maresh (1955) reference dataset. Comparison of growth patterns was conducted through assessments of height-for-age and growth velocity plots. Growth velocity was calculated as the difference in stature from one age category to the next divided by the duration of that age category. Maresh estimates for median and lowest stature of age-specific stature were converted to Z-scores using the WHO's formula based on what is referred to as a lambda-mu-sigma (LMS) method: $Z = [(X/M)^L] - 1/S \times L$ (Eckhardt and Adair, 2002), where X is the measured stature from the Maresh dataset, and M and S are the age-specific median and the generalized coefficient of variation from the WHO standard, respectively, and L ($= 1$) is the Box-Cox transformation power (see http://www.who.int/childgrowth/standards/Chap_7.pdf). The generalized coefficient of variation is derived from a Box-Cox normal transformation (when L is set to 1) of the data, which was determined by the MGRS Group to be the most appropriate for constructing growth curves (WHO Multicenter Growth Reference Study Group, 2006a). The generalized coefficient of variation, rather than the standard deviation, is used to generate Z-scores by the WHO and CDC (WHO Multicenter Growth Reference Study Group, 2006a).

The Maresh lowest measured stature for each age was converted to Z-scores because these values are sometimes used as thresholds for determining stunting using femoral lengths. If the Maresh lowest measured statures are reasonable indicators of stunting, we would expect them to fall below the -2 standard deviation threshold using the WHO growth standard. The suitability of the Maresh reference data for estimating stunting prevalence was also assessed by calculating Z-scores for a population sample of children from New Delhi, India (see Sachdev et al., 2005), using the WHO standard. The proportion of the sample that exhibited Z-scores < -2.0 represented our estimate of stunting prevalence, which was then compared with the proportion of children in that sample that fell below Maresh's lowest measured stature for each age. Maresh's lowest measured stature was used to estimate stunting because Maresh did not publish standard deviation values for stature needed for the calculation of Z-scores.

RESULTS

A visual comparison of the Maresh reference data with the WHO standard reveals similar patterns of growth for both boys and girls (Fig. 1a,b). Differences between

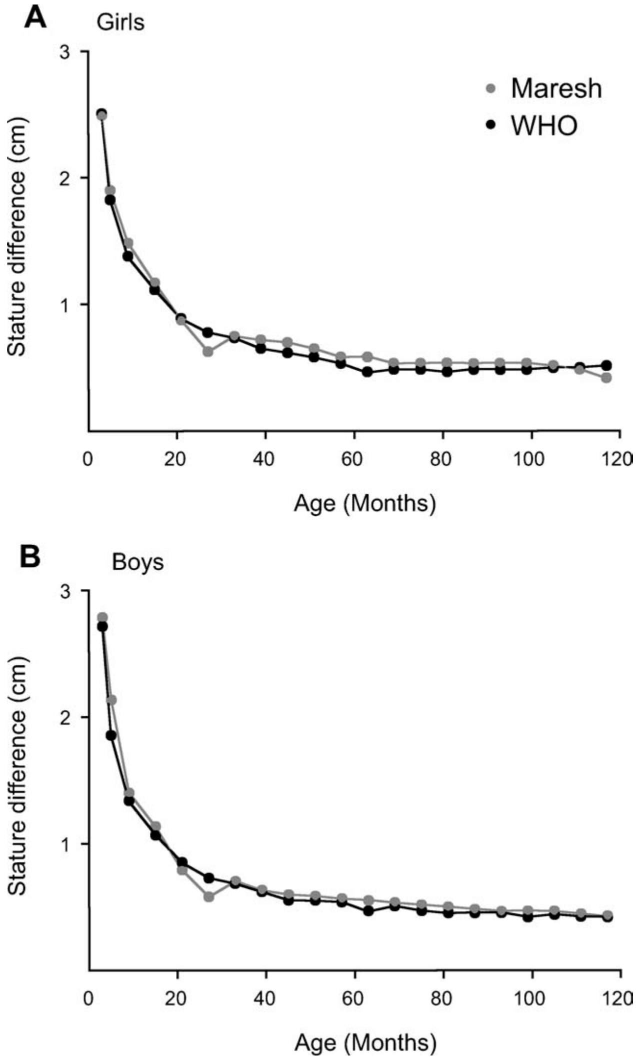

Fig. 2. Comparison of growth velocity for girls (A) and boys (B).

the two datasets are nonetheless apparent. For example, differences in age-specific stature ranged between −1.7 and +1.6 cm for boys and between −1.1 and +3.3 cm for girls (Table 1). A plot of the stature difference in the median stature-for-age in the Maresh dataset (Fig. 1c) was observed from being less than the WHO standard starting at 2 months to above the standard for girls after 48 months and at 72 months for boys. The stature differences for girls were greater than those for boys. The Maresh and WHO datasets exhibited very similar patterns and magnitudes of growth velocity (Fig. 2). The Maresh boys exhibited greater monthly growth velocity for 19 of 21 months, with the difference ranging between −1.5 and +2.8 cm per month. The Maresh girls exhibited greater monthly growth velocity for 17 of 21 months, with the difference ranging between −1.5 and +1.17 cm per month. A normal approximation of the nonparametric Mann-Whitney *U*-test indicated that for boys there was no significant difference ($P = 0.364$) in average growth velocity over 120 months between the Maresh (mean = 0.813 cm per month) and WHO (mean = 0.776 cm per month) datasets. Similarly, for girls, there was no significant difference ($P = 0.295$) in average growth velocity between the two datasets (Maresh mean = 0.816 cm per month; WHO mean = 0.785 cm per month).

TABLE 2. Comparison of the Maresh lowest stature and WHO −2.0 Z-score criteria for determining the prevalence of stunting in a population sample from India

		% Stunted		
Age (months)	N^a	Maresh lowest stature	WHO −2 *Z*-score	Difference
Boys				
2	11	10.0	18.2	−8.2
4	7	0.0	0.0	0.0
6	1,125	7.7	20.1	−12.4
12	1,239	23.0	34.5	−11.5
18	805	41.4	47.3	−5.9
24	618	58.6	51.3	7.3
30	360	54.7	46.9	7.8
36	129	61.2	40.3	20.9
42	74	64.9	39.2	25.7
48	130	74.6	39.2	35.4
54	190	73.7	38.9	34.8
60	209	72.7	40.7	32.0
66	235	64.7	33.2	31.5
72	306	68.9	35.9	33.0
78	288	56.9	26.0	30.9
84	212	51.4	30.7	20.7
90	241	48.1	26.6	21.5
96	182	38.5	17.6	20.9
102	123	38.2	26.8	11.4
108	111	23.4	18.9	4.5
114	47	31.9	25.5	6.4
120	56	30.4	17.9	12.5
Girls				
2	9	33.3	11.1	22.2
4	4	25.0	0.0	25.0
6	884	16.4	3.5	12.9
12	1,183	31.9	12.9	19.0
18	693	45.0	27.7	17.3
24	590	48.5	38.1	10.4
30	315	44.1	32.1	12.0
36	100	48.0	36.0	12.0
42	78	43.6	30.8	12.8
48	124	53.2	47.9	5.3
54	150	38.0	38.0	0.0
60	204	33.3	43.1	−9.8
66	216	32.4	41.7	−9.3
72	330	33.3	38.8	−5.5
78	208	24.5	30.8	−6.3
84	235	22.1	31.5	−9.4
90	192	22.4	41.1	−18.7
96	194	22.7	35.6	−12.9
102	133	22.6	39.1	−16.5
108	81	32.1	49.4	−17.3
114	43	27.9	34.9	−7.0
120	53	18.9	20.8	−1.9

[a] Sample size of Indian population.

The Maresh median height-for-age *Z*-scores all fell within ±1 standard deviation of the WHO median stature-for-age (results not shown). Only 5 of 22 (22.7%) boy *Z*-scores and 11 of 22 (50%) girl *Z*-scores calculated for lowest measured stature in the Maresh dataset fell below the −2 threshold used for identifying stunted individuals. It is important to note that all the children comprising the Maresh dataset were healthy, and therefore, these low *Z*-scores reflect small, though healthy, children. In other words, they represent one end of a normal range of variation for healthy children.

There were considerable differences in estimates of age-specific stunting prevalence in the Indian population based on the WHO and Maresh datasets (Table 2). For boys, when compared with the WHO standard, use of the lowest measured stature in the Maresh reference data underestimated stunting prevalence for ages 2–18 months (mean difference = −7.6%, min = 0.0%, max = −12.4%), and overestimated stunting between ages 24 and 120 months (mean difference = 21.0%, min = 4.5%, max = 35.4%). A comparison of stunting prevalence for girls revealed the opposite pattern, with the Maresh reference data overestimating prevalence for ages 2–48 months (mean difference = 14.9%, min = 5.3%, max = 25%) and underestimating prevalence for ages 60–120 months (mean difference = −10.42%, min = −1.9%, max = 18.7%).

DISCUSSION

The results of our comparison indicated similar growth patterns for the Maresh reference and WHO child growth standard datasets. Because the WHO child growth standard depicts how children from around the world should grow when free of disease and reared following healthy practices, the observed similarity suggests that the Maresh data generally reflect a typical human growth pattern for stature. Maresh (1943, p 241) reported a very high correlation (*r* = 0.9952) between stature and femoral length in her ontogenetic sample. By assuming that the pattern of median long bone growth for healthy children in a given population follows normal median statural growth, the results of the current study suggest that the Maresh dataset serves as a suitable reference for anthropologists interested in evaluating femoral growth patterns in prehistoric and historic skeletal assemblages representing different ethnic groups or geographic populations. However, it is important to note that to date, there have been no published studies comparing the relationship between femoral and statural growth across different populations. Varying relationships between juvenile long bone lengths and stature associated with population differences in relative limb proportions due to climatic adaptation have been discussed in the literature (Ruff and Walker, 1993; Holliday and Ruff, 1997; Bogin et al., 2002; Ruff et al., 2002; Ruff, 2007). Therefore, there is no way to determine that how reasonable the above assumption is regarding concordance in statural and femoral growth (see related discussions in Scuilli, 1994; Nyati et al., 2006; Smith, 2007).

CONCLUSION

The results of our study suggest that the Maresh reference data may not be as useful for identifying stunting and for estimating stunting prevalence in prehistoric populations. For both boys and girls, there were often large differences between prevalence estimates based on the WHO and Maresh datasets. The use of Maresh's lowest measured stature as a criterion for identifying stunting resulted in sex-specific patterns of both underestimation and overestimation of stunting prevalence.

Given the results presented here, significant deviations from the Maresh reference data in statural growth can reasonably be interpreted as primarily reflecting health and environmental differences, rather than ethnic or population differences. These results also suggest that the Maresh data are likely suitable for estimating age and body size in healthy children from femoral length. The use of Maresh's lowest measured stature, and possibly by extension femoral length, to identify stunting, however, may not be reasonable (e.g., Schillaci et al., 2011).

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